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Calcium alternans in a piecewise linear model of cardiac myocytes

Cardiac alternans is a beat-to-beat alternation in action potential duration and intracellular calcium cycling seen in cardiac myocytes under rapid pacing that is believed to be a precursor to fibrillation. The cellular mechanisms of these rhythms and the coupling between cellular calcium and voltage dynamics have been extensively studied leading to the development of a class of physiologically detailed models, which are often expressed as coupled nonlinear differential equations. Here we establish that the key dynamical behaviours of the model developed by Shiferaw and Karma are arranged around a set of switches. Exploiting this observation we show that a piecewise linear caricature of the Shiferaw-Karma model can be constructed that preserves the physiological interpretation of the original model whilst being amenable to a systematic mathematical analysis. We compute the properties of periodic orbits without approximation and show that alternans emerge via a period-doubling instability. We also demonstrate that when coupled to a spatially extended description for calcium transport the model supports spatially varying patterns of alternans. We analyse the onset of this instability with a generalisation of the master stability approach to accommodate the non-smooth nature of our system.